

# **Cortical Arousal Levels Influenced by Sound**

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## Abstract

Newman (1997a,b) suggests that the reticular formation's regulation of acetylcholine levels govern cortical arousal states. It may be possible to influence reticular activity and arousal states through the introduction of rhythmic sound. When rhythmic sound patterns emerge within the olivary nuclei as a coherent oscillation (objectively evidenced by an encephalographic frequency-following response), this internal oscillation (*frequency information*) proceeds to the reticular formation (Swann et al. 1982). Cholinergic neurons within the nucleus reticularis *interpret* and adapt to the intervening frequency information and in doing so alter (or stabilize) the transport and production of acetylcholine to the cortex, which consequently results in changes in (or stabilization of) cortical levels of arousal. The use of sound in the regulation of cortical arousal levels has implications in the enhancement of human performance as it relates to the control of generalized arousal levels such as the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting and vigilance, etc.

**Key Words:** reticular, frequency-following response, sound, binaural beats, brainwaves

## Introduction

Newman (1997a,b) and references therein describe the extended reticular-thalamic activating system (ERTAS) and convincingly argue that this 'conscious system' is responsible for modifying generalized levels of arousal as well as individual explicit patterns of arousal. Brainwaves objectify the scope and magnitude of this cortical arousal. When the ERTAS modifies arousal states, the individual experiences a shift in consciousness because one's first-person experience of his or her surroundings forms as a synthesis of discrete, yet cortically distributed, levels of arousal (brainwave activity) combined with specific cognitive contents. Newman (1997a) writes, "This extended reticular-thalamic activating system (ERTAS) has been increasingly implicated in a variety of functions associated with consciousness, including: orienting to salient events in the outer world; dream (REM) sleep; the polymodal integration of sensory processes in the cortex (binding); selective attention and volition." Petty (1998) writes, "The reticular activating system can be considered as, on the one hand a snoop and a gossip, and on the other as an air traffic controller. As a snoop it constantly monitors everything that is going on in the cortex (via its diffuse cortico–reticular pathways), as well as watching all the sensory input and the motor output as it goes by up and down through the brainstem. As a gossip, it tells the entire cortex what is going on (via the reticulo–cortical paths). As an air traffic controller it is responsible for watching and organizing the orderly flow of activity, and immediately alerting the appropriate entity if something unexpected or dangerous is about to occur."

Ancient cultures used sound and music to influence states of consciousness in religious ceremonies and to promote psychological and physical health. Music, rhythmic drumming, and chanting have been an essential part of most cultures' rituals. From the age of Plato and Aristotle

on into the nineteenth century the idea that sound and music influence the character of man persisted. Renowned classical and romantic composers viewed the music of their time as a powerful means of influencing consciousness and culture (Williams, 1993). Today, the idea that auditory stimulation can affect mood state and consciousness is widely accepted (Poole, 1993).

Persistent rhythmic auditory stimuli neurologically manifest as a cortical frequency-following response (Oster 1973; Smith et al. 1975; Marsh et al. 1975; Smith et al. 1978; Hink et al. 1980). This low-amplitude electroencephalographic anomaly, however, does not indicate an alteration in overall cortical arousal level. The frequency-following response simply provides objective evidence of the neurological presence of the frequency-specific stimulus. Rhythmic sound patterns appear to affect overall cortical levels of arousal by providing *frequency information* from the olivary nuclei, the first site of contralateral integration in the auditory system (Oster 1973), to the ERTAS (Swann et al. 1982).

### **The Extended Reticular-Thalamic Activating System**

The reticular formation of the brain stimulating the thalamus and cortex (referred to as the ERTAS) regulates cortical brainwave patterns. The ERTAS controls a variety of functions associated with consciousness (Newman 1997a,b; Petty 1998). The word reticular means "net-like" and the neural reticular formation itself is a large, net-like diffuse area of the brainstem (Anch et al. 1988). The reticular activating system (RAS) interprets and reacts to *information* from internal stimuli, feelings, attitudes, and beliefs as well as external sensory stimuli by regulating arousal states, attentional focus, and level of awareness which are all crucial elements of consciousness (Empson 1986; Tice & Steinberg 1989). The reticular formation stimulates the thalamus and cortex, and controls attentiveness and level of arousal (Empson 1986; Newman & Baars 1993; Newman 1997a,b; Petty 1998). "It would seem that the basic mechanisms

underlying consciousness are closely bound up with the brainstem reticular system . . ." (Henry 1992).

In the ERTAS model, the reticular furnishes the neurotransmitter acetylcholine via the thalamus to the cortex. Lower portions of the reticular formation (the locus coeruleus and the raphe nuclei) provide the neurotransmitters noradrenaline and serotonin via 'fountains' that largely bypass the thalamus on their way to the cortex (Newman 1997a). It is the balance between these neurotransmitters at the cortex that changes (or maintains) arousal levels, as measured by rhythmic electroencephalograph (EEG) patterns, and the ERTAS plays an active roll in regulating this balance.

The nucleus reticularis represents the heart of the ERTAS. It 'gates' neurotransmitter activity (*information*) to and from the cortex via cortico-thalamic projections and in conjunction with the intralaminar complex governs cortical brainwave activity (Newman & Baars 1993; Newman 1997a,b; Petty 1998). This 'gating' activity actually presents the interplay of inhibition and excitation as functions of the neurotransmitters involved. Acetylcholine, provided via cortico-thalamic projections, either inhibits or excites areas of the cortex by neutralizing or enhancing the effects of noradrenaline and serotonin coming to the cortex via 'fountains' from the locus coeruleus and the raphe nuclei.

The ERTAS governs cortical brainwave patterns with three distinct systems. First, *global activation* of the cortex for the regulation of customary arousal states, e.g., the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting, vigilance, etc., comes primarily from projections from the nucleus reticularis and the intralaminar complex (Newman 1997a).

Second, sensory input also alters ongoing arousal levels as a function of midbrain reticular activity. Sensory data compete for awareness or attention (Newman 1997b). Inputs

from the major senses (except smell) pass through the nucleus reticularis before they reach the cortex (Newman 1997b). "The major sensory modalities project to specific thalamic nuclei which, in turn, send topographically arranged projections to the primary visual, somatosensory (and auditory) areas" (Newman 1997a). It is here, within the sensory tracks that rhythmic sound appears to regulate arousal states by providing *frequency information* to the ERTAS.

Hypothetically, when the reticular formation *observes* a coherent oscillation emerging within the olivary nuclei this *frequency information* affects the cholinergic system or the 'gatelets' of the nucleus reticularis itself. This alters the membrane transport and neurocellular production of acetylcholine.

Third, there are additional cortico-thalamic projections between the medial dorsal nucleus and the prefrontal cortex. This regulatory subsystem seems to play a part in the mediation of arousal states as they relate to internal process such as emotions, selective attention, and working memory (Fuster 1980; Goldman-Rakic 1988 [both cited in Newman 1997a,b]). Perhaps through this subsystem of cortico-thalamic projections fears, worries, concerns, etc. influence cortical arousal and one's first-person experience of the world. This 'prefrontal' subsystem works in concert with the sensory and global-activation systems to provide a dynamic thalamocortical circuit that is found at virtually every area of the cortex (LaBerge 1995 [cited in Newman 1997a,b]).

### **ERTAS Summary**

The reticulo-thalamic core (the thalamus and midbrain together, the ERTAS) mediates cortical activity through the action of cholinergic neurons that propagate the neurotransmitter acetylcholine. The 'gating' ability of the nucleus reticularis appears to be the arousal control mechanism of the ERTAS. This 'gating' activity regulates cortical interplay of inhibition and

excitation between noradrenaline and serotonin from extra-thalamic activation systems and acetylcholine via cortico-thalamic projections from the ERTAS. The cortex communicates its arousal status back to the ERTAS via reciprocal projections. This *feedback* system incites the ERTAS to adjust or maintain cortical arousal levels. This *feedback* system, therefore, provides a mechanism for the cortical aspects of consciousness (experiential content) to influence arousal levels. In response to rhythmic auditory stimulus and in concert with *global activation* and internal feelings, beliefs, memories, etc., the nucleus reticularis regulates ('gates') acetylcholine levels 'projected' via the thalamus to the cortex altering arousal levels and one's first-person experience. Perhaps the reticular *sees* the intervening rhythmic stimuli (the subject of this paper) as phantom cortical activity and in an attempt to maintain homeostasis, alters arousal levels accordingly.

### **The Effects of Sound**

regulation of arousal levels by way of inducing fluxes in cholinergic neurons or the 'gatelets' of the nucleus reticularis. The concept here is that the binding of acetylcholine to cholinergic neurons (Scheibel 1980; Macchi & Bentivoglio 1986; Groenewegen & Berendse 1994 [all cited in Newman 1997a]) or the 'gatelets' of the nucleus reticularis is affected by these sounds when the rhythmic patterns become neural oscillations within the brainstem.

These changes within the cholinergic neurons can be externally initiated using auditory drubbing found in rhythmic music, drumming, or the unique phenomenon known as binaural beating. Perceived binaural beating indicates the presence of a coherent oscillation within the brainstem's two superior olivary nuclei as evidenced by the cortically measured frequency-following response (Oster 1973; Hink et al. 1980). As with other rhythmic sound patterns, the

low-level coherent oscillation (within the superior olivary nuclei) that accompanies auditory binaural beating appears to regulate arousal states by providing *frequency information* to the ERTAS and thereby inducing fluxes in cholinergic neurons or the 'gatelets' of the nucleus reticularis.

## **Binaural Beating**

A look at the auditory phenomenon known as binaural beating provides a unique opportunity to understand the power of rhythmic sound and music to influence arousal. The sensation of 'hearing' binaural beats occurs when two coherent sounds of nearly similar frequencies are introduced one to each ear. The phase differences between these sounds engender a perceived vibrato or wavering at the frequency of the difference between the two (stereo left and right) auditory inputs. This phase difference normally provides directional information to the listener but when presented with stereo headphones or speakers the listener 'hears' a third sound called the binaural beat. Binaural beating originates in the brainstem's two superior olivary nuclei (Oster 1973). Beating frequency (*information*) neurologically passes to the reticular formation (Swann et al. 1982). This information is said to be simultaneously "volume conducted" to the cortex and objectively measured by EEG as a frequency-following response (Oster 1973; Smith et al. 1975; Marsh et al. 1975; Smith et al. 1978; Hink et al. 1980). This cortical measurement was termed the "frequency-following response" because its period (frequency in cycles per second) corresponds to the frequency of the beat stimulus and the oscillation present in the olivary nuclei and subsequently the reticular formation (Smith et al. 1975). The EEG frequency-following response, an objective instrumented observation, strongly suggests that the perceived sensation of audio beating is, in fact, the result of a low-level coherent oscillation within the central nervous system and the brainstem in particular.



Binaural beats can easily be heard at the low frequencies that are characteristic of the brainwave spectrum (Oster 1973; Hink et al. 1980; Atwater 1997). The existence of an externally initiated, internally present low-level coherent oscillation (experienced as audio beating) within the central nervous system and specifically the reticular formation, suggests a condition that may facilitate alterations of levels of cortical arousal. There have been numerous anecdotal reports and a growing number of research efforts reporting changes in consciousness associated with binaural beats. The audio phenomenon known as binaural beating has been associated with changes in arousal leading to sensory integration (Morris 1990), alpha biofeedback (Foster 1990), relaxation, meditation, stress reduction, pain management, improved sleep (Wilson 1990; Rhodes 1993), health care (Carter 1993), enriched learning environments (Akenhead 1993), enhanced memory (Kennerly 1994), creativity (Hiew 1995), treatment of children with developmental disabilities (Morris 1996), the facilitation of attention (Guilfoyle & Carbone 1996), peak and other exceptional experiences (Masluk 1997), enhancement of hypnotizability (Brady 1997), treatment of alcoholic depression (Waldkoetter & Sanders 1997), and promotion of vigilance performance and mood (Lane et al. 1998).

### **Experimental Confirmation**

This experiment measured the neural accommodation (the changes in ongoing or overall brainwave activity) of a complex binaural-beat stimulus. A weak EEG frequency-following response to binaural beats manifests using time-domain averaging brainwave analysis techniques. Theoretically, the frequency-following response emerges as a low-amplitude linked series of evoked-potential responses to the binaural beats. This EEG anomaly, however, does not constitute neural accommodation. This study examined the degree to which complex

binaural beats influenced dominant brainwave activity (in this case, central delta and occipital alpha) or cortical levels of arousal, not the frequency-following response.

### Hypothesis

Listening to binaural beats for several minutes will modify ongoing brainwave activity. Increasing the amplitude of delta-frequency stimulus while decreasing the amplitude of alpha-frequency stimulus will result in comparable changes in arousal as measured by EEG.

### Method

During the experiment 20 volunteer subjects (2 women and 18 men), ranging in age from 18 to 54, remained supine in a darkened, sound-attenuating chamber. Subjects reported normal hearing with the exception of one subject who had a bilateral hearing loss for whom the volume of the stimulus was raised to a comfortable level to compensate for said hearing loss. None of the subjects reported a history of mental or nervous disorders.

The experimental binaural-beat stimuli consisted of mixed sinusoidal tones producing complex frequency patterns changing over a period of 45 minutes. The stimuli were presented with stereo earphones at 40 dB above subjective threshold. The volunteer subjects first experienced a no-stimulus baseline condition during which a 90-second EEG recording was taken. Next, each subject listened to the same 45-minute sequence of changing binaural beats (see Figure 1) during which six 90-second EEG recordings were taken at regular intervals. To reduce the influence of expectation subjects were blind as to the binaural beats presented during the stimulus condition. Finally, during a no-stimulus post-baseline condition a 90-second EEG recording was made. (see Figure 2)

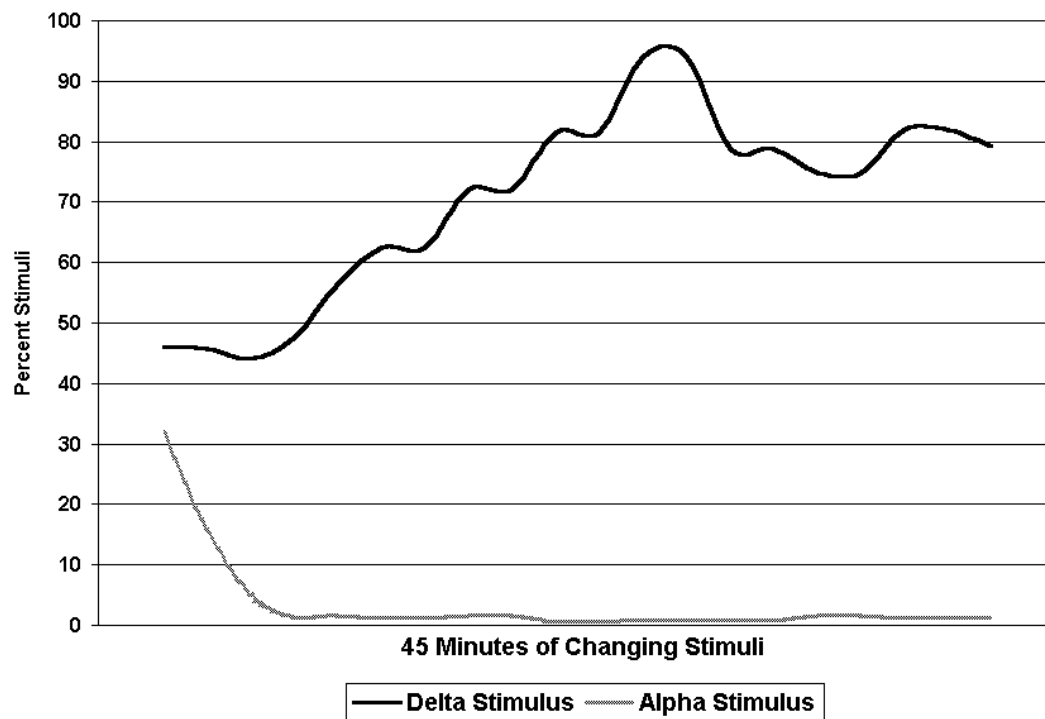


Figure 1. Changing delta and alpha binaural-beat stimuli.

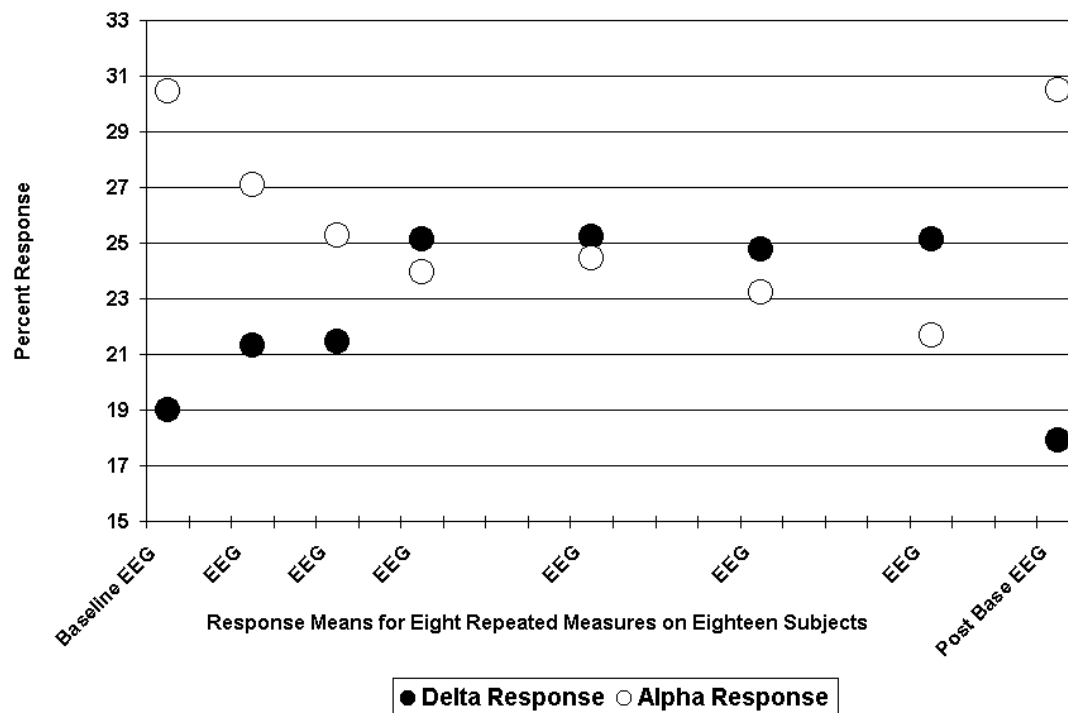


Figure 2. Neurological adaptation (arousal changes) to binaural-beat stimuli.

Subjects were connected to a 24-channel digitizing EEG computer (NRS-24, LEXICOR Medical Technology Inc., Boulder, Colorado) using V151 software and the entire standard 10/20 International System montage of electrodes. The nineteen active EEG channels and reference electrode placements were tested to ensure the lowest possible contact resistance and balanced impedance level. A sampling rate of 256 samples per second was used which provided for an EEG frequency response of 1-64 Hz (less 60 Hz, due to a notch filter), a frequency resolution of 1 Hz, and a temporal resolution of one second.

The audio patterns cross-faded smoothly from one complex stimulus waveform to another during the 45-minute binaural-beat protocol. Detailed below are the audio stimuli experienced by the subjects during the designated EEG recording periods:

<u>Left-Ear</u>	<u>Right-Ear</u>	<u>Volume</u>	<u>EEG Recording Period</u>
50 Hz	50.75 Hz	40%	First
100 Hz	101.5 Hz	32%	
200 Hz	207 Hz	28%	
50 Hz	50.75 Hz	40%	Second
100 Hz	101.5 Hz	32%	
200 Hz	205 Hz	28%	
50 Hz	50.75 Hz	40%	Third
100 Hz	101.5 Hz	32%	
200 Hz	204 Hz	28%	
50 Hz	50.75 Hz	20%	Fourth
100 Hz	101.5 Hz	18%	
125 Hz	126.25 Hz	25%	
200 Hz	204 Hz	15%	
200 Hz	202 Hz	22%	

50 Hz	50.75 Hz	24%	Fifth
100 Hz	101.5 Hz	23%	
200 Hz	204 Hz	35%	
325 Hz	328.5 Hz	12%	
525 Hz	530.25 Hz	6%	
50 Hz	50.75 Hz	29%	Sixth
100 Hz	101.5 Hz	28%	
200 Hz	204 Hz	36%	
850 Hz	858.5 Hz	4%	
1375 Hz	1397.25 Hz	3%	

analysis showed the reductions in the percentages of occipital alpha (bipolar O1-O2) during stimuli conditions were significant ( $P < .001$ ) compared to baselines. (See below.)

### **Repeated Measures Analysis Summary for Occipital Alpha**

Calculations are for eight repeated measures with eighteen subjects.

Means and standard deviations for percent occipital alpha:

1) Baseline:	mean = 30.45611	s.d. = 6.82165
2) Stim. 1:	mean = 27.09465	s.d. = 5.85853
3) Stim. 2:	mean = 25.2613	s.d. = 5.21292
4) Stim. 3:	mean = 23.94388	s.d. = 6.58925
5) Stim. 4:	mean = 24.43623	s.d. = 6.85064
6) Stim. 5:	mean = 23.22247	s.d. = 5.4852
7) Stim. 6:	mean = 21.69315	s.d. = 4.56229
8) Post Baseline:	mean = 30.48179	s.d. = 7.22964

## Repeated Measures Analysis of Variance:

Source	--S.S.--	-DF-	-MS-	-F-	Approx. p
Between Subject	3113.14	17			
Within Subject	3351.98	126			
Rep. Factor	1338.76	7	191.25	11.30	<.001
Error	2013.23	119	16.92		
Total	6465.13	143			

Error term used for comparisons = 16.92 with 119 d.f.

The Newman-Keuls multiple comparison tests showed that each stimuli condition was individually significantly different ( $P < .05$ ) than both baseline conditions.

Statistical analysis of the data also showed the increases in the percentages of central delta (bipolar C3-C4) during stimuli conditions were significant ( $P < .001$ ) when compared to baseline conditions. (See below.)

### Repeated Measures Analysis Summary for Central Delta

Calculations are for eight repeated measures with eighteen subjects.

Means and standard deviations for percent central delta:

1) Baseline:	mean = 18.9834	s.d. = 2.98245
2) Stim. 1:	mean = 21.31965	s.d. = 3.26133
3) Stim. 2:	mean = 21.45696	s.d. = 3.49995
4) Stim. 3:	mean = 25.13928	s.d. = 7.40267
5) Stim. 4:	mean = 25.21796	s.d. = 6.49606
6) Stim. 5:	mean = 24.78913	s.d. = 7.0691
7) Stim. 6:	mean = 25.13432	s.d. = 5.54435
8) Post Baseline:	mean = 17.92327	s.d. = 3.07973

## Repeated Measures Analysis of Variance:

Source	--S.S.--	-DF-	-MS-	-F-	Approx. p
Between Subject	1748.32	17			
Within Subject	3096.16	126			
Rep. Factor	1121.88	7	160.27	9.66	<.001
Error	1974.28	119	16.59		
Total	4844.48	143			

Error term used for comparisons = 16.59 with 119 d.f.

The Newman-Keuls multiple comparison tests also showed that stimuli conditions three, four, five, and six were individually significantly different ( $P < .05$ ) than both baseline conditions.

### Experiment Summary

The results of this experiment significantly ( $P < .001$ ) distinguish EEG activity during the stimulus periods from the baseline EEG recordings both with increased central-delta activity and decreased occipital-alpha activity. Decreases in alpha amplitudes coupled with increasing delta activity indicate reduced cortical arousal (Berger et al. 1968). The mounting changes over the course of the stimuli suggest a deepening trend of progressive relaxation and falling asleep. Some altered states of consciousness are also associated with increased delta (Empson, 1986) and a suppression of occipital alpha.

A basic question raised by this study was the role of binaural beat-stimulation in solely or directly causing the state changes observed. Several of the subjects had considerable previous experience with binaural-beat audio recordings. It may be that the subjects in this study were naturally adept at altering levels of arousal or they acquired this ability through repeated practice. Additionally, the deepening trend over time suggests taking naturally occurring, progressive state changes associated with falling asleep into consideration. Plans are to run another twenty

subjects through the same protocol using non binaural-beat producing tones during the stimulus periods.

The possibility remains that the binaural beat has a direct effect on the reticular formation as outlined above. Such a direct effect would involve the interaction of binaural-beat stimulation with the basic rest-activity cycle, other sensory stimulation, and with "higher order" memory or attentional processes also under the *scrutiny* of the reticular formation. All of these systems cooperate to maintain homeostasis and optimal performance in what is hoped to be the best interests of the individual. Natural state changing mechanisms (Steriade, McCormick, & Sejnowski, 1993), ultradian rhythms, individual differences, prior experience, and beliefs may all contribute to the effects of and response to binaural beat stimulation as they do with nearly all other behaviors.

## Discussion

Some have referred to the apparent effect that music, rhythmic drumming, or audio beats have on brainwave states as being the result of *stochastic resonance*, a nonlinear cooperative effect. This stochastic resonance model is inappropriate within this context however because, as the model states, even though a small amount of noise added to a much larger signal can greatly increase the response to the signal, a weak signal added to a much larger noise will not generate a substantial added response (Adair 1996). Within the brainstem, audio stimuli (e.g., music, rhythmic drumming, or binaural beats) are not seen as 'a small amount of noise' being added to 'a much larger signal' but as 'a weak signal' (an internal coherent oscillation as evidenced by the frequency-following response) being added to 'a much larger noise' (ongoing brainwaves).

Although the thrust of this paper is concerned with the regulation of arousal levels through the use of deliberately induced coherent sound stimuli, the regulation of brainwave states



by means of incidental or prevailing sounds in the workplace or home environment cannot be overlooked. The rhythmic mechanical sounds of machinery or electronic devices may enhance or impair task vigilance or work performance (see Lane et al. 1998). Background sounds may affect mood and sense of well-being.

## **Conclusion**

This paper promotes the understanding of the role of the ERTAS in altering cortical levels of arousal in the presence of rhythmic sound patterns. Further, experimental work is offered that provides statistical observations in support of the notion that rhythmic sound patterns (binaural beats, in this case) appear to engender changes in cortical arousal that can be objectively monitored with the EEG. As the reticular is responsible for regulating cortical arousal (Swann et al. 1982; Empson 1986; Newman & Baars 1993; Newman 1997a,b; Petty 1998), it is possible that the reticular formation serves as the mechanism of change in arousal levels engendered by externally initiated (e.g., music, rhythmic drumming, or binaural beats) coherent oscillations within the superior olivary nuclei and further the cholinergic neurons within the nucleus reticularis. Additionally, four decades of investigation have shown that exposure to such stimuli under appropriate circumstances can provide access to expanded states of consciousness (Atwater 1997). Several free-running EEG studies (Foster 1990; Sadigh 1990; Hiew 1995; Brady 1997, among others) suggest that binaural beats induce alterations in cortical arousal states. These cited studies also document measurable changes in the ERTAS during exposure to binaural beats because the reticular formation is exclusively responsible for the regulation of cortical arousal. See Swann et al. (1982), Empson (1986), Newman & Baars (1993), Newman (1997a,b), and Petty (1998). It would appear that the rhythmic frequencies of an auditory stimulus (when objectively demonstrated by an EEG frequency-following response)

affect cholinergic neurons within the nucleus reticularis. Such an intercourse modifies the membrane transport and production of acetylcholine and consequently results in changes in arousal states. These suppositions are compatible with current knowledge of the reticular formation and suggest a neural mechanism, an instrument for the regulation of cortical levels of arousal using rhythmic audio stimuli.

The implications in the enhancement of human performance as it relates to the control of generalized arousal levels such as the basic rest/activity cycle, sleep cycles, mood and motivational states, orienting and vigilance, etc., are intriguing. This paper encourages further research and the responsible application of existing technologies providing access to propitious states of consciousness.

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